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ADVANCED ELECTRICAL POWER GENERATION AND DISTRIBUTION CONCEPTS --ETC(U)

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6 ADVANCED ELECTRICAL POWER GENERATION AND DISTRIBUTION CONCEPTS FOR MILITARY FACILITIES.

by

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FOREWORD

The investigation presented in this report was supported by funds for "Investigation of Materials for Permanent Construction," Office of the Chief of Engineers, under Task "Power Systems Design Methodology," work unit "Power Plant Construction." Work was performed at the offices of Arthur D. Little, Inc., Cambridge, Massachusetts, under the cognizance of Mr. Morris J. Pollock in the Electrical Mechanical Systems Laboratory, U. S. Army Construction Engineering Research Laboratory (CERL), Champaign, Illinois.

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ADVANCED ELECTRICAL POWER GENERATION

AND DISTRIBUTION CONCEPTS FOR MILITARY FACILITIES

PART I: INTRODUCTION

The loads on the electrical power systems of military facilities and installations have increased rapidly over the past several years. The increases are a result of increased use of sophisticated technical equipment, emphasis on a comfortable, well-housed, military population and the developments in small appliances and accessories which can be conveniently carried with personnel as they are transferred from post to post. Most of the increased technical load has evolved in areas such as data processing, communications and weapons systems which have both high demand and a need for high quality, high reliability electrical power sources.

Commercial power sources are also undergoing rapid load increases in the civilian sector. In addition, economic and social factors have caused an irregular pattern of development of commercial power resources. The emphasis now being placed on pollution control on all fronts has resulted in severe repercussions on capacity expansion, causing delays in putting new generating equipment into service and in the provision of needed transmission and distribution facilities. This has caused lower reliability of commercial power, and at the same time, has resulted in increased costs.

Special military facilities involving computers, communications, radar and similar equipment must be provided with reliable, high quality power independent of external influence and environment to perform their mission. Thus, the commercial power available in some cases cannot meet the requirements of military power systems and in other cases exceeds the cost of on-site generation. The use of total energy systems which utilize excess heat from power production facilities for heating and cooling functions provides additional economy favorable to on-site power production.

The present study will provide an assessment of feasible concepts of providing electrical power systems, generation, and distribution, for fixed and semi-fixed military facilities in the 1980-1990- time frame. Information which is produced by this study will be used to incorporate advanced technology, and improvements in equipment and systems into future military facilities power systems.

Direction of the Study

In the preparation of this preliminary report, we have reviewed the relevant conventional and advanced power and distribution systems that hold promise of satisfying the stated requirements. We have considered the full range of power generation systems ranging from fully developed diesel electric systems to yet-to-be-invented magneto-hydrodynamic generators. In the area of distribution we have reviewed conventional distribution systems and developing systems in the area of extra-high-voltage transmission and superconducting systems. Because of the power ranges, conversion costs and distribution distances that are required to make a number of these advanced systems economical under presently prevailing conditions, they do not appear to be directly relevant to the present study.

In the area of advanced generation systems, our future emphasis will be on direct conversion and fuel cell systems since they appear at this time to be particularly adaptable to the power ranges of interest. A smaller effort will be devoted to nuclear and magneto-hydrodynamic systems so that we can provide the necessary availability, technical or economic arguments for justifying our selections. A similar small effort will be carried on in the investigation of advanced distribution systems so that the selections and the reasons for making them will be well justified.

PART II: COMMERCIAL AND UNINTERRUPTIBLE POWER SYSTEMS

Commercial Power

As commercial power will continue to be a major source of electrical energy for military facilities within the foreseeable future, it is highly important that the characteristics of this power be known and documented. This power will be generally applied to non-critical loads such as lighting, operation of machinery, and non-critical communication and computer applications. It is necessary that the characteristics of this power be well understood to determine the effects which it may have on the more critical operations as well as those of a conventional nature. Techniques for the improvement of reliability and quality of commercial power should also be well understood to obtain best practicable performance in the event that commercial power is the only available source for even critical operations under a given situation. For these reasons, we propose to develop information on the following items in this field:

1. Normal Operating Tolerances

We are primarily concerned with the basic factors of voltage regulation, frequency regulation, and wave form of the commercial power. While the basic characteristics of commercial electric power are maintained at a high quality in close tolerance at the point of generation, the effects of transmission and distribution can have adverse effects on all but frequency deviation, and even in this case momentary frequency deviations can be caused by sudden changes in power factor. The effects of the transmission and distribution system and the loads associated with them can, however, have considerable effect on the quality of power at the point of usage.

2. Unusual Deviations

While in the above section we deal with normal operating tolerances, those which are to be expected when a system is operating within its designed limits, one must also consider the unusual deviations from these limits which can occur in the event of system or local disturbances. Such events as major power outages of long duration, short-term power outages of the order of a few cycles to a few seconds where central station switching or automatic transfer corrects the problem, very short-term outages of less than a few cycles duration which usually go undetected but can have adverse

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effects upon computer and communications equipment, voltage and frequency swings caused by unusual application of loads or fault currents, high or low-voltage transients caused by lightning strokes, and similar occurrences are worthy of identification, definition, and evaluation. It is usually these events which cause our greatest trouble in critical use of electric power and most of the characteristics of the electric power supplied and the requirements of the equipment using this power must be compatible to assure reasonable reliability and performance.

3. Reliability of Service

If an installation has been in operation for an extended period of time, detailed knowledge of the reliable history of this installation can give valuable information as to its predicted future reliability. Even with this knowledge, major errors in prediction of reliability can be made for several reasons; i.e., inadequate data was taken during this history of operation to provide the degree of accuracy necessary for new equipment, particularly, system changes have been made which would effect future operations in an adverse manner, or more exacting requirements now exist for which data was not or could not have been taken previously. Clearly, a capability beyond projection of a system operating history is necessary, and in the event of a system which is new, is the only means for predicting future reliability. As each installation is unique to itself, it is not practical to furnish blanket reliability figures for commercial power. Much is known, however, about the causes of deviation from normal design tolerances. With this knowledge, updated by recent experience and investigation, we can provide a set of criteria for determining the relative reliability of a specific power installation. This prediction can be greatly improved in accuracy by careful investigation of the local situation using techniques which we have found to be most effective. Once we have predicted the reliability of a specific power installation and compared this to their requirements for this installation, we can proceed, where necessary, to various means for improvement of this power supply.

4. Reliability Improvements

Considerable improvement in reliability can be accomplished by the application of various recently developed techniques which show promise of continuing improvement. These techniques fall short of installation of standby generation equipment, continuous-duty

generation equipment, or any of the various uninterruptible power supply systems. Where the requirements are so demanding that no power interruptions or deviations of any type can be tolerated, then a true uninterruptible power supply must be installed. These systems are discussed elsewhere in this report.

The most common type of problem encountered, particularly in remote areas, is excessive voltage variation. Where voltage variations of a relatively long-term nature occur, such as over a period of several seconds or more, station or line-type voltage regulators can be used. Recent improvements in these include solid-state controls and improved contact life to assure high reliability. These units are capable of regulating voltage at relatively high power levels. Where higher speed regulation is required, of the order of several cycles' time response, resonant magnetic and static voltage regulators are available. These are being rapidly improved and information with regard to present and protected future capabilities of this equipment will be included. At the present time, these high-speed regulators can handle only limited amounts of power, of the order of several kva. We will furnish basic characteristic information on both conventional and high-speed static regulation equipment of present and projected future designs. The other area in which major improvements can be achieved is by use of redundant primary feeds into a distribution system. The simplest technique of this type is two primary feeders with an automatic transfer switching system which will transfer from one feeder to another. In this case, when one feeder fails, the other feeder takes over within a few seconds at most. An interruption does occur at this time. For even greater reliability, it is possible to use dual feeds with dual transformers with secondaries paralleled through network protectors. With this approach, both feeders and transformers are operating continuously, but the system can continue to perform satisfactorily in the event of failure of either feeder or transformer. The network protector disconnects the transformer at fault from the system and permits continuous power at the secondary. Considerable work is being done at this time in the area of improved network protectors and network transformers, and this information will be presented. A further discussion of these network techniques will be found in the section Distribution Systems under the subject of Spot Networks, a system most appropriate to reliable power distribution in military facilities requiring relatively large amounts of reliable power.

The reliability of a system is also highly dependent upon the mechanical and electrical integrity of the distribution system. These factors will be considered under the subject Distribution Systems.

Uninterruptible Power Systems

The application of high-speed digital computers, particularly in the on-line mode, and the requirements for critical communications equipment have placed new and severe demands upon the power source. In many cases, commercial power is of inadequate quality to meet these requirements. It is typical for a digital computer central processing unit to begin power-down in the event of a two millisecond power interruption. This is merely a small transient within a one-half cycle wave envelope. A transient of this type may be caused by capacitor switching, line or transformer energizing currents, a remote lightning stroke, faults on associated transmission or distribution feeders with subsequent circuit breaker clearing, and several other common causes. These occurrences can be quite frequent on a remote system and sufficiently frequent on a solidly interconnected system as to be quite troublesome. The trend in correction of this type of problem has been the uninterruptible power supply system. Many types of these systems are available and constant improvement is occurring within the industry. We have been particularly close to this work as a result of extensive work in the design and installation of computer centers and their uninterruptible power systems. Our knowledge in this area is highly current, and we are constantly looking towards the improvement of this equipment. Several major improvements in this equipment have resulted from our designs and newly established requirements. Essentially, an uninterruptible power supply system furnishes power to a critical load from a source completely independent of the commercial power on a minute-to-minute basis. Complete buffering from the commercial power source is a requirement, and the result is the production of continuous and well-controlled power of a type most suitable for computer and other critical usage. Several approaches are now used to accomplish this end, and constant improvements in the area of static devices indicates that these will be the devices of the immediate future. The several types of equipment which are and will be available are quite different in performance, cost and operation; so it is well worthwhile discussing each of these separately to permit proper evaluation for each particular application. As each application is unique, careful consideration must be given to the requirements and the matching of uninterruptible power supply equipment to the equipment to meet these requirements.

1. Standby Generation

In many applications, the primary requirement is continuously available power, but an interruption in the order of several seconds causes no serious disjuncture in operations. Where

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commercial power is satisfactory for operation under normal conditions, standby generator units can be used for emergency requirements. The most popular units in present use are diesel engine generators and gas turbine generators. While the diesel engine has been used for many years, the gas turbine is rapidly coming into popular use. We will consider both types of units with their relative advantages and disadvantages as well as the future trends in improvement of both units.

2. Rotating Machinery UPS

When the requirements for uninterruptible power became evident, the immediate solution was use of a local alternator to supply this power. As an alternator and its controls can be made reasonably reliable, all that was necessary was to assure a reliable driving means for the alternator to provide the required power. If the alternator output was dedicated to supplying the critical load only, then other disturbances which normally effect commercial power would not exist. There are many techniques and combinations for achieving uninterruptible power using these techniques. As these systems are relatively economical in capital cost and reasonably reliable for use where the ultimate in performance is not a necessity, they should be discussed and defined for consideration in any critical power application. At the present time, there is relatively little development being done on equipment of this type. It is well developed, and it has probably reached its peak of performance as static equipment (to be discussed below) is receiving the major thrust of development effort.

The output of each system is essentially identical. A high-quality alternator is used to produce either 60 Hz or 400 Hz power with satisfactory wave form, suitable voltage stability, and adequate transient response. Brushless exciters working in combination with solid-state voltage regulators are standard in these installations. Present designs are limited to the use of a single generator for optimum reliability. Techniques for the use of alternators in parallel where the failure of one alternator would not affect the critical bus have not been developed. While it is entirely practical to parallel units when the additional load requires this capacity, one must be aware of the fact that the overall system reliability has been downgraded by the parallel operations. Where true redundancy is required, the static systems have been highly developed to provide this feature.

The differences between the various configurations exist in the way that the alternator shaft is driven. A common technique is

to drive a 1200-rpm alternator by means of an 1800-rpm low-slip induction motor through an eddy current clutch. The eddy current clutch controls the speed of the alternator to maintain correct frequency. A flywheel mounted on the motor provides ride-through for time periods of the order of 10-30 seconds. In the event of a short power failure, the flywheel energy is supplied to the alternator with the eddy current clutch holding alternator speed at 1200 rpm while the flywheel decelerates. Where longer term support is necessary, a diesel engine is coupled through the motor shaft through an over-running clutch. After a power failure of 1-2 seconds, a command is sent to start the diesel engine. This engine will start within 8-10 seconds and accelerate the flywheel-motor back up to 1800 rpm where it will continue to operate until power is restored.

Another approach is to convert commercial power to DC, usually using modern solid-state devices. This DC is used to drive a DC motor which drives the alternator directly. A large storage battery is floated on the DC line and supplies the motor anytime commercial power has been interrupted. Support times of the order of 30 minutes are reasonable with a system of this type. In the event support for longer periods is desired, a diesel generator can be used which may be started after a significant power interruption and used to supply the input rectifiers.

Other alternatives available are the direct use of diesel engine generators to supply critical loads, these generators being dedicated to the critical load only, or the use of gas turbines to drive critical load generators in the "total energy" configuration. This total energy technique has an economic attractiveness in the case of computer installations. As considerable air-conditioning is required for these installations, the energy for this air-conditioning is obtained by utilizing the exhaust heat from the turbines to operate absorption chillers. While a system of this type can be considerably more reliable than commercial power, one must consider that the failure of any turbine, generator, or control unit associated with them can cause failure of the entire system as it is a parallel non-redundant configuration.

3. Non-Redundant Static Systems

With the advent of the silicon-controlled rectifier, the newly developed solid-state static inverter became a possibility. With this device it is possible to produce alternating current from direct current at relatively high power levels and efficiency. The wave-form distortion can be maintained within satisfactory limits,

voltage regulated rapidly and accurately, and frequency controlled precisely or varied at will. Transient capability is relatively low when compared to rotating machinery, however. Of particular attractiveness in the UPS requirement is its high reliability, with reliabilities of the order of 20,000 hours MTBF readily achieved.

Using a force-commutated static inverter as the basic unit, a relatively straightforward system can be built to provide uninterruptible power service. Commercial power is brought into the area and rectified using an industrial-type voltage controlled SCR type rectifier to produce direct current. This direct current is used to supply the static inverter. A large station battery floated on the DC line provides a ride-through capability of several minutes to several hours as required. Where longer ride-through requirements must be met, a diesel engine generator can be used to supplement this power by supplying the rectifier with its required alternating current.

The above-described system has, of course, several single-point failure modes which could cause loss of power on the critical bus. To provide power to the critical bus in the event of failure of any of these elements or to make it possible to take the static equipment out of service for maintenance, it is necessary to provide a bypass system. Using techniques similar to paralleling alternators, one can adjust the frequency and phase of the inverter to match that of the incoming commercial power line. Through the use of automatically interlocked circuit breakers a closed transition transfer from inverter to commercial power can be made allowing shutdown of the inverter without interruption of power to the critical bus. While operating on bypass, the system is exposed to the expected problems when using commercial power and is usually done during a non-critical operating period.

The above type of bypass is only useful in taking an operating system out of service or in restoring power after the operating system has failed. It is possible by monitoring the inverter SCR users to determine when an inverter has failed and identify this fact in a period substantially less than one millisecond. Most critical installations are not affected by disruptions of the order of one millisecond, so it is possible to take appropriate action. ADL has recently developed a high-speed switching technique which makes it possible to bypass a failing single inverter system from the critical bus and supply this critical bus with commercial power on a no-break basis. In this system, the inverter is phase-locked to the commercial power line. In the event of a detected inverter failure, a high-speed static switch is closed which connects the commercial power line to the critical bus. At the same time a

command is issued to commutate a high-speed static switch normally connecting the inverter to the critical bus, disconnecting the failing inverter. Transients of wave form of the order of less than 10% peak voltage and shorter than one millisecond are typical in this type of transfer. The critical load is not affected. In the event of a failure of this type, the inverter may then be repaired while the system is operating on commercial power and restored to service without interruption.

4. Redundant Static Systems

Where commercial power is highly unreliable or the ultimate in uninterruptible power supply systems is required, a redundant static system is dictated. As larger critical loads usually require several inverters operating in parallel, an additional inverter of the same size can be used as a stand-by unit. All inverters are operating on-line continuously. Each inverter supplies its appropriate share of the load to the critical bus through a high-speed static switch. The control system of each of these static switches monitors its inverter. In the event of an inverter failure, it operates to disconnect that failing inverter from the line in a time less than one millisecond. The remaining inverters pick up the additional load, and the critical load is unaffected. The inverter may be repaired and returned to service. During the time in which one inverter has been removed from service, the system is exposed to the possibility of failure of a second inverter and attendant critical bus failure. Judgment must be applied as to whether it is more appropriate to expose the system to this second-order failure mode or bypass the system to commercial power and operate in that manner during repair of the inverter.

While it appears uneconomical to furnish an additional inverter for redundant operation, another economic factor supports the appropriateness of a redundant system. In normal operation of large systems, the starting transient of a major element will be such as to require additional inverter capacity over and above the normal running capacity. This is used only when a large central processing unit or memory device is being started. Essentially, this additional capacity must exist even without a redundant requirement. By using the redundant inverter to supply the starting transient capacity, it serves two purposes. In the event of a failure of one inverter, one must then be particularly careful to maintain system configuration so that an unusual starting transient would not cause critical bus voltage depression or bypass the system to commercial power to start a large portion of the system. As the failure of an inverter is a very remote occurrence, this is not an unreasonable burden to place on the operating personnel.

PART III: DISTRIBUTION SYSTEMS

Distribution systems are used to provide power at primary voltage levels in concentrated urban areas, rural areas of lower load density, and to commercial or industrial areas where the requirements are sufficiently widespread as to preclude efficient secondary power distribution. While distribution systems by definition involve voltages below 69 kv and above 480 volts, the most common distribution voltages are 13,800, 7,200/12,500, and 2,400/4,160 volts. The 13,800-volt level is most commonly used in concentrated urban areas where relatively large blocks of power must be distributed in underground or limited space overhead systems. The 7,200/12,500-volt level is commonly used in rural areas and is the voltage generally applied to distribution transformers in these locations. The 2,400/4,160-volt level is an older design still finding wide application in residential areas, particularly where overhead installations must be used and the problem of running these lines through tree branches is common. Several present and promising distribution techniques and systems are proposed to be considered in this study as follows:

Conventional Overhead Wire Distribution

The conventional distribution system using wooden poles, cross-arms, pole top pins, and bare or weatherproof wire has been in use for several generations. In many areas it is highly economical to install, easy to maintain, and provides adequately reliable service. It has been highly developed over the years, and only modest improvements have been made within the past 10-20 years. Because of its wide popularity and high degree of development, the various elements of this system will be described in reasonable detail.

Overhead Close-Spaced Wire

This is an improvement over the conventional overhead wire distribution system. In this case, two, three, or four weatherproof or bare wires are mounted on special brackets in a closely spaced geometric configuration. To preclude these wires swinging together between suspension points, insulators are mounted at regular intervals to provide adequate spacing. As this system represents a measurable improvement and has both technical and economic advantages over the conventional open-wire system, it and its logical successors will be discussed in detail.

Overhead Spacer Cable

A further improvement in the overhead distribution system is represented by the overhead spacer cable. While similar in content to the overhead close-spaced wire, there are many applications in which even closer spacing is desired, and/or protection from tree branches is critical. In this case, fully insulated cable is used in a very close-spaced configuration, this spacing being maintained between suspension points by insulating spacers. This is probably the most economical of the cable installations, and for this reason will also be covered in detail.

Overhead Messenger Cable

The most compact of the overhead distribution systems is a cable installation in which the several insulated phase conductors are bound to a neutral by means of flat metal tape. The neutral can be either ACSR, Copperweld, or a combination of copper and steel conductors to provide both neutral conductivity and cable support. Properly installed, this system can provide high strength and reliability associated with minimum visibility. It is also quite invulnerable to interference by tree branches if it must be installed in a wooded area. Where appearance is a major consideration and economics or terrain are such as to preclude installation of underground distribution cables, the messenger cable provides a good compromise. Because of the wide use of this system where a "good neighbor policy" is important, we plan to describe it.

Underground Distribution Systems

This is the most rapidly growing distribution system being installed today. Rapid progress is being made in the improvement of performance and reduction in cost of the various elements included for underground use. Numerous combinations of equipment are possible including underground primary cable, underground or overhead secondary conductors, buried or pad-mounted area transformers, pad-mounted unit transformers, etc. Installation is also a major factor and must be considered. Underground distribution is a systems problem and must be considered as such. The various parts and installation techniques must be appropriately integrated to provide a system of maximum reliability and reasonable installation costs. Presently, underground distribution is used primarily to enhance appearance of the area. It does, however, show considerably greater reliability ~~in~~ than overhead systems and for this reason, if no

other, should be considered seriously for more critical military facilities. Because of the extensive development effort being applied to this approach and the rapid improvements being achieved as a result of this development, we will not only describe the present equipment and installation techniques but project well into the future to provide meaningful data for future planning in possible underground distribution systems.

Spot Networks

In highly concentrated load centers such as downtown urban areas, it has been common for some years to use a secondary network distribution system with multiple primary feeders. In this type of installation, a secondary grid, commonly 120/208 volts, is laid out along each city block with interconnections at every street intersection. This installation is usually underground. At these nodal points, distribution transformers are connected to feed the network, often two at each point. These transformers are supplied from several independent primary feeders, also usually underground, so that the loss of any single feeder will only reduce the capacity of the network and not disable it. Each transformer is equipped with a network protector which opens the circuit in the event of reverse current or transformer failure. In addition to being able to handle a considerably greater load density, considerable improvement in reliability is achieved over the conventional radial systems. It has recently become apparent that a similar technique can be used in smaller areas and even in individual large buildings where two or more transformers equipped with multiple input feeders and network protectors can provide high levels of reliable power. These installations are known as spot networks and would be very appropriate to concentrated military facilities. Because of their usefulness and high rate of improvement, these spot networks will be covered for present and projected future developments.

Unit Type Equipment

In addition to the wiring, whether it be overhead or underground, there are numerous major units which make up a distribution system. These include such devices as transformers, circuit interruption equipment, lightning protection, primary switching devices, and power metering.

Some transformer styles have been available for many years. The original pole-mounted transformer is still used in its earlier

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configuration with improvements in efficiency and reliability. More recently, the completely self-protecting pole-mounted transformer has come into wide use. This transformer includes overcurrent protection for both primary and secondary as well as lightning protection all in an integrated package. For underground distribution systems both the vault-type and pad-mounted transformers are available. For large and spot networks, special network transformers are built using network protectors as an essential part of this installation.

Usually current overprotection and switching devices are combined in distribution systems. These devices usually fall into the categories of fused cutouts, oil or air-blast circuit breakers, reclosing circuit breakers, and sectionalizers. As these devices are essential to any distribution system, it is important that the present devices be described and projections be made as to the direction to be taken in new equipment to become available within the next 20 years.

Metering of one form or another is usually an integral part of a primary or secondary distribution system. A brief discussion of the several metering techniques is appropriate to cover this area of interest.

System Protection

Any distribution system which has been properly designed has received careful attention in the areas of protection from such occurrences as overloads, faults, and lightning. The coordination of cable size, transformer capacity, fuse sizes and types, circuit breaker relay settings, and lightning arrester location and breakdown voltage are critical in the establishment of a safe and reliable installation. The various techniques which have been found to be effective and economical will be discussed to provide a reasonable criteria for system planning.

Wire and Cables

Because they are so critical to any installation, we propose to include a discussion of the various types of overhead bare and insulated wire conductors and the several types of underground cables which would be appropriate to primary and secondary distribution.

PART IV: CONVENTIONAL POWER SYSTEMS

Diesel Engine

The diesel engine of today represents a very mature power plant concept, with a long history of competitive application in power development. Its design and performance capabilities are well defined and a high degree of standardization has been achieved. Nevertheless, technical development of diesel engines continues to yield improvements in design, and hence in the high efficiency that is, along with its ability to use a wide range of fuels, its principal competitive advantage. As time goes on, further gains in cycle efficiency, power to weight ratio and reliability can be expected but at a diminishing rate. While acknowledging some improvement in its performance variables, it is reasonable to expect that the diesel engine in the foreseeable future will be designed much the same as those in service today, enjoying the same advantages and subject to the same limitations. The economics of diesel power generation, as in all other engines, depends upon the cost and availability of suitable fuels, in this case oil and gas. Changes in fuel costs will, therefore, have a corresponding effect on the diesel economics, and it is primarily in this area that changes in the competitive position of the diesel are likely to occur.

Specifically, further increases in the specific power of diesel engines will probably be achieved through increased turbocharger pressures and design modifications in the engines, allowing higher combustion pressures and cylinder work outputs to be accommodated. Improvements in turbocharger efficiencies and engine design will allow further lowering of specific fuel consumptions. The engineering problems and outlays needed to solve the problems identified with these advances will increase and corresponding gains appear smaller and smaller. Nevertheless, engine designers are actively engaged in these areas of potential advance and higher engine rating are being advanced as a result. Where load demands are compatible, more efficient utilization of the heat produced by the combustion of fuel can be had by incorporating the diesel in a total energy system. In these systems the heat released to the water jackets and the engine exhaust is recovered in heat exchangers and put to useful purposes such as producing hot water, space heat or absorption air-conditioning.

Gas Turbine

The gas turbine is in a stage of evolutionary development wherein betterment of its performance characteristics are taking place relatively rapidly compared to the diesel. Gas turbine performance at the present time is limited mainly by the heat resistance of materials in hot, highly stressed engine parts. Mechanical, thermodynamic and aerodynamic performance factors are well understood. Gains in engine efficiency now and in the future will depend on achieving higher peak cycle temperatures and exploiting various means of exhaust heat recovery. The most advanced gas turbines now available for industrial use and operating on the simple cycle have peak cycle temperatures in the 1600°F to 1800°F range and specific fuel consumptions of 0.50 to 0.60 pounds per horsepower hour.

In the 1980-1990 time frame, we would expect the peak cycle temperatures to range upwards from 2000°F to 2200°F, these higher temperatures made possible by use of better heat resistance materials and turbine blade cooling. Commensurate with these higher cycle temperatures there will be an improvement in specific fuel consumption to the 0.40 to 0.50 pounds per horsepower-hour range. This specific fuel consumption can be compared with 0.34 to 0.37, which is typical of the diesel engine. Further improvements in overall thermodynamic efficiency can be obtained by incorporating some form of waste (exhaust) heat recovery. One form of waste heat recovery utilizes a heat exchanger (a regenerator or recuperator) which is made to exchange heat between the exhaust products and the air entering the combustor. This is the so-called regenerative gas turbine thermodynamic cycle. Other versions incorporate a heat exchanger in the gas turbine exhaust to produce steam for additional power (combined steam and gas turbine cycle) or for space heating or absorption air-conditioning.

One attractive feature of the gas turbine, particularly the simple cycle version, is its high specific power, that is, its high power output per unit of size and weight. This feature makes it particularly adaptable to mobile or semi-mobile applications. In any case, it minimizes the needs for site preparation prior to its installation.

Combined Cycle

In the combined cycle the heat present in the exhaust of a gas turbine is utilized to make steam which, in turn, is expanded

in a steam turbine to produce more power. The steam boiler may be fired or not. When the boiler is not fired, the power system goes under the acronym STAG (STeam And Gas).

The main advantage of the combined-cycle plant is its high thermodynamic efficiency. Heat-rate gains over conventional steam plants typically can range from 3 to 9% depending on unit size. In a study carried out by General Electric, they designed an optimized 19-mw output STAG gas-fired plant. This plant had a predicted thermal efficiency of 35.9%, an efficiency 14% higher than and a first cost competitive with a conventional steam unit of comparable output. As another example of the validity of the combined steam and gas turbine approach to power plant design, the San Angelo Power Station, San Angelo, Texas is cited. This station generates 128 mw at a heat rate of 9270 Btu/kw (36.8% thermal efficiency) net based on the higher heating value of the natural gas fuel. In this station the boiler is supplementary fired and has a steam turbine capable of 103 mw and a gas turbine capable of 25 mw. The efficiency of the San Angelo unit is comparable to the largest and most efficient power plant of many times its size. The cost of this unit was $86.50/kw or at a cost which compares favorably with conventional steam units of comparable size.

In common with the conventional steam plant, a combined cycle plant must be located at a site having sufficient water available for cooling in the condenser. Thus, the need for cooling water places a limitation on its use. Also, in common with the conventional steam plant, the combined cycle plant can give rise to a problem of thermal pollution. However, this problem is not regarded as very significant for the plant sizes considered in this study.

Conventional Steam

The economics and technology of conventional fossil-fueled steam turbine plants are well established. In a slowly developing technology, the trend is to supercritical boilers (3200 psia) and peak cycle temperatures in the 1000-1100°F. For commercial power units the trend is to ever larger capacities where the economies of scale are realized. Future technological development calls for increasing plant efficiencies mainly through designs for higher peak cycle temperatures. This will be a slow evolutionary process where, at each step of the way, an optimum balance will be sought among the variables first cost, plant efficiency and plant reliability.

The large amounts of water needed to cool the condenser section of the conventional steam plant can be considered a limitation to its use as the power plant site must have sufficient water available for cooling. As a rule of thumb, it takes approximately 1/2 gal/min of cooling water circulating through the condenser for every kilowatt of output from the plant. In flowing through the condenser, the cooling water is raised to a temperature of about 90°F. If returned directly to its source, it gives rise to local heating and may upset the ecology of the local waters. This is a condition known as thermal pollution. While thermal pollution is viewed as a real problem for power plants with capacities measured in hundreds of megawatts, it is a relatively minor problem for plants having capacities up to 50 mw as considered in this study.

Hydroturbine

The development of power from water falling through a hydroturbine has been reduced to a time-honored practice. The efficacy of such a power system in application to military facilities depends entirely on the fortuitous location of the facility in a site where water power can be made available. As the chance for such an occurrence will be relatively rare, we do not propose to investigate the application further.

PART V: ADVANCED POWER SYSTEMS

In this portion of our report we have carried out a brief review of the existing and developing technology in a number of advanced power system concepts, including the following:

- Nuclear-Steam Generators
- Direct Conversion
  Thermionic
  Thermoelectric
- Magneto-Hydrodynamics
- Fuel Cells

In addition to these primary power generation means, we have also reviewed existing and developing battery technology. The demand for uninterrupted power for a number of critical military applications will undoubtedly require the installation of highly reliable backup battery power supplies.

It should be emphasized that this preliminary report is a general technology review. In this first overview of the technology relevant to the specific military requirements, we have not limited our investigation only to those particular systems that are designed to operate in the required power ranges. When this review is completed, we plan to identify those particular power generation methods which hold promise of satisfying the particular military requirements of interest in this study. To the extent possible, we will provide a comparison of the potential alternatives as to time of availability, costs, and reliability.

Nuclear Steam Generators

Nuclear (fission) steam generators do not compete with fossil-fueled steam generators below 6-700 mw(e) at present except in areas of high fuel costs, e.g., 40¢/million Btu or more where they compete at about 300 mw(e)[(1)]. This results from the high fixed cost of shielding, reactor containment, and spent fuel handling and storage facilities which are not much affected by scale. As a result, virtually no development is being done at the moment (in this country) on units capable of producing less than 1000 mw(e). The exception to this is, of course, steam generators for use in

submarines which are rated at about 20 mw. However, it is apparent that fuel costs for this class of reactor are very high. Jane's Fighting Ships (1970/1971) estimates fuel costs at $0.15/kw hr[2]. Although these costs may decline through production efficiencies, fuel enrichment charges have been increasing.

Most steam-generating reactor systems being built or proposed today are boiling water (BWR), pressurized water (PWR) or heavy water (HWR) types. This last type is not produced in the United States.

Present plans call for the introduction of the liquid-metal-cooled fast-breeder reactor (LMFBR) as a steam generator some time in the 1980's.[3]. This depends on the progress of continuing development programs. Breeder reactors produce more fissionable material, the nuclear fuel, than they consume by converting non-fissionable uranium (or thorium) into fissionable isotopes. Continuing growth of nuclear fission power generation in the 1990's and beyond will probably depend on the availability of fuel produced by breeder reactors.

Under present conditions nuclear-fired steam plants require about 25% more cooling capacity than an equivalent fossil-fueled plant due to limitations on maximum fuel temperatures and consequent reduced thermal efficiency. It is probable that this difference will be reduced by 1980/90 through advances in metallurgy. Efficiency of Rankine cycle fossil-fueled plants will not increase materially during this interval since they now operate in a temperature region where the strength and lifetimes of materials are critical. However, the addition of "topping" systems using, for example, MHD generators which exhaust gas at 600°C or so would result in a combined total thermal efficiency of up to 60% using fossil fuels.

Direct Conversion Thermionic-Thermoelectric

The Atomic Energy Commission has for the past decade carried on a large and continuing program in conjunction with NASA on the development of thermionic and thermoelectric methods of directly converting heat to electricity. A briefing by the staff of the Atomic Energy Commission responsible for these programs has been arranged so that we can obtain up-to-date information on these developing technologies. This briefing has been scheduled for the month of March.

Primary efforts in thermionic conversion has been directed toward developing the necessary materials technology so that one can construct a thermionic-nuclear-reactor fuel-element that provides a direct electrical output from the reactor core. Individual thermionic conversion cells and multiple cells in the form of test reactor fuel element have undergone in-core tests. Through these tests it has been possible to find solutions to the in-core materials problems to the point that these test cells now provide lifetimes of thousands of hours.

Work on thermoelectric conversion has largely been directed toward small instrument power supplies for NASA. AEC-supported work in this area has been directed primarily toward isotope-powered systems. These developments now provide highly reliable power sources whose lifetimes are now measured in terms of years.

In addition, NASA has carried on a program for the past decade on photo-voltaic direct conversion systems that have resulted in reliable space hardware with lifetimes of the order of one year or more. These systems are designed for direct conversion of solar energy to electrical energy in space. Because of the variability and uncertainty in atmospheric conditions on the earth's surface, it is doubtful that these systems would be useful for terrestrial applications.

Magneto-Hydrodynamics

Practical magneto-hydrodynamic power conversion has not yet been demonstrated. However, it is expected to become an important component of very large fossil-fueled power plants in the future if development proceeds as expected. As present efforts are directed towards use in very large systems, it is an unlikely base load power conversion mechanism within the terms of this study.

MHD power conversion potentially offers relatively fast response as a back-up power source within the power range of concern. The economics of such systems are uncertain, due to the early state of development and an intensive study of current experimental progress is warranted.

Open-Cycle Gas Magneto-Hydrodynamic (MHD) power conversion is called a "direct conversion" system because the thermal energy in a heated gas is converted to usable electrical energy without recourse to a rotating generator. Heated gas is allowed to expand through a nozzle accelerating the gas to a high velocity whereupon

it is allowed to flow between electrodes in a region of a high transverse magnetic field. Thus, electric charge carriers (electrons and ions) are deflected by the magnetic field and collected by electrodes connected to an electrical load. The charge carriers are provided by a thermally ionized material with which the hot gas is "seeded."

Intensive research programs are in effect in Europe, Japan, the United States, and the USSR, with the aim of applying this technique to the national power grids.[4] The reason for the wide interest in MHD is that it appears to promise a 20 to 30% increase in efficiency in central power station efficiency when used in combination with a steam generator and turbine, that is, an increase in efficiency from the present 40% to about 50%. This is achieved because MHD systems operate well above the critical temperature of steam so that the exhaust gas from the MHD generator can be arranged to be at an optimum temperature to heat steam for use in a conventional Rankine cycle turbine-generator.

Published results to the present are encouraging; and there seems to be no major barriers to eventual commercial success, very likely in the 1980's. The construction of a 75 mw(e) combined MHD-steam pilot plant has already been announced in the USSR.

The commercial availability of MHD systems in this country will depend on the rate of funding of research and development. Factors affecting this rate include increasing pressure on the utilities to reduce pollution and cooling effluent as well as fuel costs. Since the use of MHD in conjunction with steam plants would produce a marked improvement in these areas, it is possible that this R&D will be accelerated in the next few years.

The performance of MHD power generators improves with size, due to increased ratio of volume to surface area. In addition, the fixed capital costs of such devices are high; they require large (superconducting) magnets, regenerative gas heaters and DC to AC power conversion.

The result is that most current development is directed towards very large units to be used in combination with steam turbine generator systems.

Work in this field in the United States has been done at Atomics International, Avco, Westinghouse R&D, Arnold Engineering Development Center.

MHD (Liquid Metal)

MHD power conversion using a liquid metal as the charge carrying fluid in place of a plasma or a gas carrying an ionized salt is attractive because it allows operation at lower temperatures, and permits operation as an induction machine eliminating the need for and serious problems associated with conducting electrodes and also the problem of DC to AC conversion. These advantages stem from the high conductivities of the various liquid metals (normally liquid sodium/potassium mixtures). However, conversion from thermal energy to kinetic energy requires expansion of the liquid through a nozzle resulting in a high vapor content in the liquid metal reducing its conductivity sufficiently to render the process impracticable as yet. Much of the current research in this field deals with this aspect of the technology.

MHD power conversion using liquid metals is probably further from commercial application than open-cycle plasma MHD schemes. The principal motivation for continuing development of liquid metal systems is for space application where power density (power per unit weight) is paramount.

Fuel Cells

Although fuel cells of a size suitable for power generation in military facilities are not yet commercially available, fuel cell development as a whole is sufficiently advanced that it is now possible to predict with some confidence their operating characteristics and availability. Prospects are reasonably good that commercialization of large fuel cells will be achieved in the late 1970's and that they will present a practical alternative for stationary power generation in the 1980-1990 time period.

As is the case with batteries, fuel cells convert chemical energy directly into electrical energy; the principal difference being that fuel cells operate on the basis of a continuous flow of oxidant and reductant (fuel), whereas, batteries operate on a batch basis. The advantages of fuel cells over dynamic power sources include higher fuel conversion, efficiency, typically 50-60%, lower noise, vibration, and pollution levels, low heat signature and a lack of major moving parts. This last characteristic suggests that high reliability may be obtainable, once the technology matures. Disadvantages which have so far hindered acceptance of fuel cells include the high first cost of many types of systems due to the requirements for noble metal catalysts, short operating life

due to poisoning of catalysts, corrosion of cell materials, and failure of auxiliary components such as pumps, valves, etc. Many of these problems are associated with the relatively early stage of development of fuel cell technology and can be expected to diminish in the future.

Fuel cell development, which for practical purposes has a history of less than fifteen years, has in the main been directed at three application areas:

- Power systems for space vehicles, the capacities generally being in the range of 0.5 to 5.0 kw.

- Small power sources, particularly for remote sites, the requirement being for capacities of 0.1 to 1.0 kw.

- Stationary power sources for relatively large-scale power generation, capacities being in the range of from 10 to several hundred kilowatts.

Space fuel cells operate on cryogenic hydrogen and oxygen and, while highly reliable, are far too costly to be considered for terrestrial applications. The technology for small power sources has involved the use of hydrazine as a fuel because of its high reactivity and physical convenience. Hydrazine is costly (yielding an energy cost of about $10/KWH), and these systems cannot be considered for larger scale applications. Replacement of hydrazine by methanol is a possibility; but the reactivity of the latter in fuel cells is poor; and while further improvements may occur, methanol fuel cells presently require too much noble metal catalyst to be practical. For economic reasons, fuel cells for larger scale power generation necessarily operate on hydrocarbons; and it is this segment of the technology which is of principal interest for power generation at military facilities.

Hydrocarbon fuel cells can be classified as either "direct" or "indirect." In direct systems, the fuel, mixed with steam is reformed and reacted in the anode compartment of the cell. Elevated temperatures (500-700°C) are required, and such cells use molten carbonate electrolytes, generally stabilized rheologically with a ceramic additive to form a stiff paste. While a number of groups have worked on this approach in the past, the only program presently active in the United States is that at the Institute of Gas Technology (IGT) where a fuel cell with an output of one kilowatt is now under construction.

Indirect hydrocarbon fuel cells use a steam reformer or a thermal cracking unit to generate hydrogen from the fuel, the hydrogen then being fed into an ambient temperature, aqueous electrolyte fuel cell. The separation of the fuel reforming and energy conversion steps, although involving a more complex system, avoids the quite formidable materials problems of elevated temperature operation and presently appears to be the more attractive approach. Pratt and Whitney (P&W) Division of United Aircraft Corporation is the most prominent group working in this field, and is currently supplying the U. S. Army Electronics Command with prototype units rated at a few hundred watts, which use common liquid logistic fuels, such as gasoline. More significant, however, is a program at P&W which has been carried out for several years under the sponsorship of the gas industry. Operating under the acronym TARGET (for Team to Advance Research for Gas Energy Transmission), it aims to develop a 12.5 kw system utilizing natural gas as fuel, to be used for local generation of electricity in apartment houses and even in individual homes. Funding is at a level of several million dollars annually. It is understood that the demonstrated lifetime of the fuel cell units is over two years and is expected to be longer. The fuel cell unit itself can generate peak capacities of up to 10 kw per cubic foot, although the total volume of the 12.5 kw system, including reformer, inverter and controls, is about 30 cubic feet. With present technology, system costs are estimated at about $300/kw for quantity production; but this is expected to be lowered as experience with the system grows.

Outside the United States the only major fuel cell program which might possibly have relevance to the military base requirement is that being pursued by the French company, Alsthom, an affiliate of the large electrical conglomerate, CGE. Alsthom's approach has been to improve upon conventional hydrazine fuel cell technology by pumping the electrolyte rapidly through very narrow closely spaced cells, thus achieving very high power densities. An affiliate of Standard Oil Company (New Jersey) has recently joined with Alsthom in the financing of a new $10 million, five-year program which will attempt to extend this approach to methanol-based cells. If successful, such technology might conceivably become a candidate for military base power generation in special circumstances.

Batteries

While the central power-generating systems of a military base would undoubtedly contain an adequate supply of spare components,

if not of entire systems, to cope with outages caused by breakdowns, maintenance, etc., it is likely that for critical applications such as communications links and data processing equipment standby energy storage systems would also be required to provide uninterrupted service during switching operations and to give added protection in the event of malfunction of the back-up generators. Dynamic energy storage systems, such as flywheels, only offer protection for at most a few hundred cycles; static systems using batteries can conveniently provide reserve power for periods of up to about ten hours. Static UPS (uninterruptible power system) installations consist of a rectifier, a storage battery and an inverter and have been designed in capacities of up to 1000 kw. Their cost, however, is substantial, being on the order of about $500/kw in sizes of 100 kw and up and more in the smaller sizes. About 20% of the cost is attributable to the (lead-acid) storage battery which is sized to carry the full power load for a specified time period. Clearly, for a given installation, the outage period which can be covered can be doubled by doubling the size of the battery, which would increase costs by about only 20%.

A survey of future technology applicable to power generation at military bases should for completeness include a section on the selection of batteries for UPS installations. The choice at present rests between various subcategories of the lead-acid and nickel-cadmium systems. In general, the latter are smaller and more economical only when outages of less than five minutes are being anticipated. For most UPS installations, lead-acid batteries with lead-calcium grids are used because of their lower requirement for maintenance, particularly water addition. The Bell Telephone System has in the past made extensive use of batteries of this type, incorporated as back-up power in its direct-current powered telephone exchanges. Difficulties arising from unexpectedly premature grid swelling and case fracture caused Bell to develop and introduce a novel type of stationary lead-acid battery having horizontally mounted conically shaped grids of almost pure lead. The grid was designed to minimize the undesirable consequences of expansion as the battery ages, and these new batteries are predicted to have a service life of about 15 years. It is possible that the Bell design will also be used for UPS installations.

Other uses of batteries in the power systems of military facilities are also possible by the 1980's. They may achieve a more general function as a back-up energy reservoir particularly if (a) the cost of inverters falls substantially (which seems likely), or (b) DC generators such as fuel cells, thermoelectrics, or thermionics, become established as the prime power system. The

increased use of DC transmission systems will also promote the usefulness of batteries as power system components in reserve power and in peak shaving functions.

A significant limitation on the use of batteries even in DC systems is their cost, which even for the lowest cost industrial quality lead-acid system, averages about \$70/kw and \$50/kw. Of potentially great importance for stationary power system applications is the development of high-performance, high-temperature, alkali-metal batteries which are presently being investigated for prospective use in electric vehicles. If these batteries, such as the sodium-sulphur system of Ford, Yuasa and others, the lithium-chlorine systems of GM and SOHIO, and the lithium-sulphur systems of Argonne National Laboratories, become practical for the vehicle application they are likely to have a cost in the range of \$10-\$30/kw. At that cost level, they should be of great interest for many DC power installations. Monitoring of these research and development programs on advanced batteries is therefore proposed for inclusion in this survey of power-generating systems.

PART VI: FACILITIES CONSIDERATIONS

With our present basic knowledge of the field of power supply, generation, and distribution, we do not foresee any highly significant developments within the next 20 years which would have gross effects on our study and recommendations as they will appear in the final report. We will, however, make every effort to uncover new developmental ideas which could be brought to bear effectively in the solution of your electrical supply and distribution problems. In the area of solid-state power conversion equipment as used in other interruptible power supply systems, we have quite a different situation. Very rapid progress has been made within the past five years, and we expect that this will continue. We feel that we can make quite useful predictions as to the general nature of this equipment in the next ten years and some serious speculation on its nature at the end of 20 years.

In examining the various facilities which are to be considered, the following is a listing of these various facilities, with their approximate power requirements and the several methods of supplying these requirements as they are immediately suggested. The actual systems to be considered are described in more detail in other parts of this preliminary report and will be thoroughly covered in the final report.

Data Processing Facilities, 250-1,000 kw

The requirements for data processing vary from the simplest type of batch processing to highly critical on-line computer installations. Batch processing computers have been regularly operated quite successfully on commercial power where reasonable reliability and quality is achievable. If this is unsatisfactory, power from diesel engine or turbine generator units is quite satisfactory. Where systems become more critical, then an uninterruptible power supply system must be installed which will supply high-quality power on a continuous basis. While it is possible to use rotating machinery systems in the 250 kw range, the total range of 250-1,000 kw strongly suggests that static power conversion equipment should be used, supplying this power in a redundant system or for the smaller units in a high-speed static transfer system.

Communications Facilities, 250-5,000 kw

For less critical requirements, it is usually quite practical to operate communications facilities and equipment from commercial

power. Where continuous supply of power is critical, one can either use standby generation in which diesel engines or gas turbines of appropriate size could handle the maximum requirement in this case, or to use on-site generation with a sufficient number of units to provide long-term reliability. It may be necessary, where critical digital data processing is involved, to use a higher quality of power such as would be obtained from a static inverter or dedicated motor generator set.

Emergency Power Systems, 250-2,000 kw

Emergency power systems in this size category are usually small enough so as to limit them to conventional engine or turbine generators unless unusual circumstances exist. For long-term use in a readily accessible fixed base, one should consider the conventional diesel engine generator. Where mobility is highly desirable or accessibility is limited, then the gas turbine has a clear advantage due to its considerably lower weight per kilowatt. Balanced against this is its higher fuel consumption, however. Where transportation of fuel becomes a major problem, one can consider a small nuclear plant, but the cost of a unit in this size would be prohibitive for most installations. Also, the initial weight of the installation would be very high. Included in the emergency power systems should be the necessary operating and control switchgear such as voltage failure detection relays, generator and commercial power circuit breakers and transfer switches, automatic starting system, and starting battery chargers or air compressors.

Protective Shelters, 250-1,000 kw

Shelters of this type in which the power is used for lighting, heating, air-conditioning, and conventional machinery and equipment operation can be supplied for any of several initial sources. Distribution to an installation of this size must almost of necessity be at primary voltage levels. Transformation to secondary distribution could be by a single three-phase transformer, three single-phase transformers, or two network transformers where additional reliability is desired. In the event power is to be generated locally for a protective shelter of this type, it would most logically be generated at secondary distribution voltage level by one or more diesel engine generators or one or more gas turbine generators.

Contingency Power Systems, 2,000-50,000 kw (Including Fixed Floating Plants)

For a fixed location where the site is readily accessible, one could consider one or more diesel engine generators, one or more large gas turbine generators, a steam turbine or combined cycle plant, or even a small nuclear plant. Where transportability is highly desirable or accessibility is limited, power at this level is optimally generated by the medium size gas turbines. These are trucks or air transportable and can be operated in parallel to provide the desired capacity. For fixed floating plants, future predictions indicate that these will probably be limited to gas turbine installations because of their low weight and simplicity of installation and operation.

Administrative Facilities, 250-2,000 kw

Facilities of this type and size would generally be handled in a manner similar to that indicated in the above paragraph, Protective Shelters.

Logistics Facilities, 2,000-25,000 kw

Distribution throughout a facility at the 2,000 kw level can be achieved by a single transformer setting and secondary voltage distribution from that point. Even at 2,000 kw it is, however, somewhat marginal due to the high currents involved. For this reason, one should consider primary distribution for facilities of this size. In this way, the power is taken to a point of concentrated usage at the primary level and transformed down to secondary voltages in blocks usually no more than 1,000 kw each. The power source can be either commercial power or on-site generation. Where commercial power is used and emergency generation support is required, this emergency power can be generated at secondary voltage levels by smaller units and installed only where the requirement is critical. This approach considerably reduces the total capital cost for installed emergency generation equipment and provides some diversity rather than a single large unit to supply all requirements.

Post, Camp, and Stations from 2,000-50,000 kw

Power at the upper level of this range is in the category of a moderately sized urban area. Fifty thousand kw if distributed

at 13,800 volts would require currents of approximately 2,500 amperes, clearly too much power to be distributed conveniently at this voltage level. For this reason, these larger installations would require substations operating at somewhat higher voltages than this, such as 69,000 volts, then transforming down to a convenient primary distribution voltage, distributing at this primary voltage, and then further transforming to secondary voltage levels at the focal points of usage. Power for installations in this size category would generally be obtained from commercial power sources, on-site diesel engine generators, or gas turbine generators. At the upper end of the range, conventional steam, combined cycle and nuclear power plants can be considered. Fifty thousand kw is still relatively small to make a nuclear plant economical unless the transportation of fuel is an overruling factor. Also, a nuclear plant of this size would be essentially a single-unit installation with the inherent problems of shutdown for refueling and maintenance requiring standby power from other generation sources or commercial power.

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